

Evaluation of Safety Distances for UXO Disposal Operations

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Abstract

In this paper an evaluation of danger areas to be evacuated during UXO disposal operations will be made. It is based on the following research programmes currently underway at the TNO Prins Maurits Laboratory (PML).

- An evaluation of the safety distances prescribed in the currently-used Dutch directive concerning evacuation distances for UXO disposal operations has been made. The main conclusion of this study is that the safety distances for different net amount of explosive charge show little consistency. It is suggested to conduct a risk analysis to determine new guidelines for safety distances.
- A study is underway on blast propagation and interaction with multiple urban structures. The main objective of this study is to provide a simple practical model which describes the influence of obstacles, like buildings and houses, on the propagation of blast waves. This model can be used to improve guidelines for blast damage to residential areas. Preliminary results have indicated that due to shielding, safety distances can be allowed to be smaller than follows from present-day risk analysis, which is based on the free-field pressure decay of the blast wave.
- The main results of an experimental programme aimed at developing a bomblet or mine attenuator will be described. This attenuator can be placed over small UXO-items to protect EOD personnel and vulnerable objects against explosion effects. By using this kind of protective tools the safety distances for UXO disposal operations on small ordnance items can be reduced. Within this framework also the reduction of confined explosion effects by water has been examined.

Keywords Blast waves, Blast interaction with structures, Blast damage assessment, Explosion effects, Safety distances, Mitigation effects

1. Introduction

In a densely populated country, like The Netherlands, it is important to know safety distances as accurate as possible because of the risks communities living close to ammunition storage sites are exposed to and because of the enormous cost involved in the evacuation of people during UXO disposal operations. For the determination of danger areas around ammunition storage depots, in the Netherlands a risk analysis is conducted. By means of this risk analysis, the risk for people situated beyond a certain radius from the depots can be determined. As a result, an indication of the number of casualties to be expected in case of an accidental explosion can be obtained. By comparing the risk calculated, with the accepted societal risk as prescribed by the Government, the hazard for surrounding communities can be evaluated.

An essential step in the risk analysis is the quantification of the explosion effects. For an accurate prediction of the risk, it is essential to be able to predict the decay of the blast and fragmentation effects with distance as accurate as possible. The equations describing the airblast parameters as well as the fragmentation effects are obtained from data gathered from High Explosive tests using charge weights varying from a few kg to over a few tons.

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As the next step in risk analysis, the magnitude of the consequences, like damage to structures or injury to people, is predicted. Some knowledge on structural damage has been obtained from large explosion trials and bomb damage records which have been reported in the U.K. during the second world war. Obviously, with the use of new materials in building industry these data might need to be updated. To predict the consequences for human beings so-called probit functions have been developed at TNO-PML, based on experimental data found in literature and obtained from own experiments.

In this paper several projects related to the determination of safety distances for UXO disposal operations will be described:

In the Dutch Directive "Collection of Common Directives for the Army nr. 19" (in the following referred to by its Dutch acronym VGVK 19) regulations are given for safety measures to be obeyed by Explosives Ordnance Disposal (EOD) personnel during UXO disposal operations. In this document, guidelines for safety distances, enclosing danger areas to be evacuated during UXO disposal operations, are described as well as protective measures to protect people, buildings and installations. The safety distances reported in the VGVK 19 are based on "old data". Therefore, on behalf of the EOD organization, a study was initiated aimed at developing better, more reliable guidelines for safety distances. In analogy with the approach for the storage of ammunition, TNO-PML has suggested to conduct a risk analysis to determine new guidelines for safety distances. In the present paper the first phase of this study will be described.

The second project described in this paper is concerned with improving the prediction of the characteristics of the blast wave as it moves away from the explosion source and propagates through urban areas. Current risk analysis is based on the strength of the undisturbed pressure wave: i.e., damage and risk contours are related to the free-field decay of the peak overpressure with distance from the explosion source. Due to the shielding effect of houses on the edge of a city, however, the blast will be attenuated resulting in a reduction of the damage to the rest of the city. This modification of the blast wave due to the interaction with surrounding urban structures has not been accounted for in present-day risk analysis. This deficiency has a significant effect on damage-assessment and the determination of safety distances.

The third project described in this paper is concerned with protective measures which can be taken to reduce the extent of evacuation area. When clearing minefields, the threat of random detonations of surrounding mines endangers the EOD personnel working in the field. Hence, there is a need for a blast and fragment attenuator, which can be placed over mines lying in the vicinity. Such an attenuator should capture most of the fragments of an exploding mine and vent the blast away from the demining personnel. The attenuators can also be used to protect vulnerable objects situated close to the mines. TNO-PML has initiated an experimental research programme aimed at developing such a "mine attenuator". The results of some preliminary tests will be presented in this paper. Within the framework of this study the effectiveness of water to reduce explosion effects has been examined experimentally by placing water bags over the vent opening of the attenuator.

Another project related to the evaluation of safety distances is concerned with the development of directives for safe storage of ammunition and explosives for military operations Out-Of-Area, see the paper by Van Dongen (1996) included in the Conference Proceedings.

2. Evaluation of evacuation distances prescribed in the VGVK 19.

In the past, much effort has been put into developing guidelines for safety distances for permanent ammunition storage. Little attention, however, has been given to assessing safety distances for UXO disposal operations. Only in the following documents guidelines for safety distances to be considered during UXO disposal operations have been found: the ARMY TM 60A-1-1-4 dated 1964, in which Explosive Ordnance Disposal Procedures for the American EOD personnel are described, and the Field Manual FM no. 9-16, dated 1968.

2.1 Summary of evacuation distances given in the VGVK 19 and the TM 60A-1-1-4.

The evacuation distances described in the VGVK 19, and the corresponding scaled distance $Z=R/W^{1/3}$ are summarized in the following table.

Size UXO	radius [m]							
W [kg]	Buried				unburied			
	war		peace-time		war		peace-time	
kg	m	m/kg ^{1/3}	m	m/kg ^{1/3}	m	m/kg ^{1/3}	m	m/kg ^{1/3}
< 25	50	17.1	75	25.7	50	17.1	75	25.7
65	50	12.4	75	18.7	75	18.7	115	28.6
125	75	15	115	23	100	20	150	30
250	100	15.8	150	23.9	200	31.8	300	47.7
500	150	18.9	225	28.4	250	31.5	375	47.3
> 500	250	31.5	375	47.3	400	50.4	600	75.6

Table 1. Prescribed evacuation distance for different net amount of explosive [VGVK 19].

The distances given in the table indicate danger areas to be completely evacuated. According to VGVK 19, danger areas to be partly evacuated start at the border of the completely evacuated region and ends at twice that distance.

In the TM 60A-1-1-4 the following minimum precautions to be taken for the disposal of a buried and an unburied UXO weighing up to 3000 pounds are described:

For a buried UXO:

- evacuate all steel reinforced buildings within 30 m (90 ft), and all unshielded rooms facing the incident area within 50 m (150 ft).
- evacuate all other buildings within 50 m (150 ft).
- allow no wheeled traffic within 50 m (150 ft).
- open all doors and windows within 100 m (300 ft).

For an unburied UXO weighing 100 to 3000 pounds:

- evacuate all buildings within 100 m (300 ft.)
- evacuate all unshielded rooms within 200 m (600 ft).
- allow no wheeled traffic within 150 m (450 ft).
- open all doors and windows within 500 m (1500 ft).

For peace-time 50% greater evacuation distances should be applied. In general, the Dutch regulations prescribe larger evacuation distances for heavy UXO's than those given in the TM 60A-1-1-4.

2.2 Discussion of regulations prescribed in the current Dutch Directive VGVK 19

One of the deficiencies of the current Dutch Directive VGVK 19 is that it is not clear on what data the safety distances reported in the VGVK 19 are based. By comparing the quantity-distance tables in the VGVK 19 to those included in the TM 60A-1-1-4, it was found however that most of the QD-tables in the VGVK 19 were derived from data reported in the TM 60A-1-1-4. In the introduction of the TM 60A-1-1-4 it is stated that some of the tables, e.g. on blast damage, are based on the old M-series of US GP bombs. Therefore, these tables are not to be considered as definitive for other ordnance types, and are intended only as a rough guideline and might have to be up-dated.

The tables which describe radii of earth-shock damage for GP bombs, e.g. on buried steel or concrete pipes or building foundations, as given in the TM 60A-1-1-4 and the VGVK 19, are based on “the manual of bomb disposal” published in 1941 in the U.K. Obviously, with the use of new materials in current building industry, the correctness of these data is doubtful. Perhaps, new large scale explosion trials with representative GP bombs and different underground structures are needed.

From Table 1 it can be seen that the scaled distance for low net amount of explosive is smaller than for high explosive weight. For small charge unburied UXO's, in peace-time the scaled distance for the evacuation area is of the order of the IBD for the permanent storage of ammunition, which is about $Z = 22.2 \text{ (m/kg}^{1/3})$ in accordance with NATO/AC 258. For larger net amount of explosives and vulnerable buildings, like hospitals and schools, a safety distance of $Z = 44.4 \text{ (m/kg}^{1/3})$ is recommended, which equals more the values given in Table 1 for larger explosive weights. There seems to be no clear relation between the safety distance given for certain amount of explosive charge and the explosion effects expected.

No motivation for the factor 2 between the outer bound for the completely and partly evacuated region has been given in the document. Furthermore, one may question whether this partly evacuated area is practicable. According to regulations, people who stay in the partly evacuated region should remain in rooms that do not face the UXO. However, civilians will be curious and will be tempted to observe the disposal operation leading to dangerous situations. Since the police is also forced to take cover it is hardly possible to supervise this regulation. Hence, the partly evacuated distance should better be removed from regulations.

Another regulation states that windows and doors should be opened in the evacuation area, as to minimize possible blast damage. Because the risk for theft is considerably higher than the risk of an accidental explosion, the police is tempted to advice to lock all windows and doors, increasing the risk for severe blast damage.

Beyond the danger area to be partly evacuated, there is a region where people in the free field have the risk of being injured by fragmentation, debris or flying glass. Hence, in this region, no people are allowed in the free-field. According to VGVK 19, the guidelines for the fragmentation distance as given in Table 2 should be considered.

net amount of expl.	fragmentation distance [m]	
[kg]	war-time	peace-time
< 25	125	190
125	275	425
250	400	600
500	500	750
750	750	1150
> 750	1200	1800

Table 2. Fragmentation distances

In the TM 60A-1-1-4, for several types of GP bombs, predicted fragmentation distances are given. For bomb case fragments, distances of up to 1.200 m have been found, and because of their aerodynamic shape, for the nose section, base plate and suspension lugs distances of up to 2.000 m should be accounted for. These distances hardly vary with weight of the explosive charge of the bomb, as opposed to the case for the fragment distances given in the VGVK 19. In general larger fragment distances are reported in the TM 60A-1-1-4 than given in the VGVK 19. Hence, the fragment distances reported in the VGVK 19 should be reconsidered.

2.3 Discussion of an alternative approach for the determination of safety distances.

Summarizing the remarks made in Section 2.2, some of the guidelines for evacuation distances given in the VGVK 19 are questionable and there is a need for a more consistent approach for the determination of safety distances. As suggested by TNO-PML, an alternative approach is to, first, quantify the effects of a possible detonation, and next to determine the safety distance on the basis of a risk analysis. Hereby, the risk for people situated beyond a certain radius can be calculated and compared to an accepted risk level as prescribed by the Government. Such an approach has already been used for the determination of danger areas around permanent ammunition storage depots, dangerous industries in the Netherlands.

It is suggested to calculate the effects of different types of ammunition, e.g. GP bombs, artillery and mortar rounds, by using the CONWEP program. CONWEP is a collection of conventional weapons effects calculated from the equations of the TM 5-855-1 "Fundamentals of Protective Design for Conventional Weapons". It can be used to calculate the airblast, fragment penetration and ground shock for different types of detonations, e.g. surface burst, partially or fully buried. Also the fragment penetration in target materials of concrete, steel, wood and soil can be calculated as well as the ground shock in various soils, varying from loose dry sand to heavy saturated clays. Hence, CONWEP is ideally suited to calculate the explosion effects from different UXO items.

For the determination of danger areas around permanent ammunition storage depots the program RISKANAL has been developed at TNO-PML. RISKANAL is based on "the Manual of NATO Safety Principles for the Storage of Military Ammunition and Explosives"(AC 258) for the prediction of explosion-effects and on "the Green Book" concerning the consequences of explosion effects for people and environment. The program calculates the internal and external safety of an ammunition storage site. The risk involved can be obtained by the product of these calculated effects and the probability of the accidental event. Comparing this calculated risk with the applied rules for acceptable risks results in the acceptance or rejection of a hazardous situation.

As input the total number of surrounding objects, the average number of human beings per object, the type of surrounding object (e.g. inhabited building with less or more than four floors, unprotected human beings or public traffic routes) should be specified. Public traffic routes are defined by the 24 hours intensities of both cars (protected people) and cyclists/pedestrians (unprotected people). Next, the physical effects due to the explosion are quantified. For each surrounding object the side-on pressure and impulse, the positive phase duration, the radiation intensity and the exposed time are calculated. With these quantified physical results, the effects on human beings are calculated by means of probit functions as described in the Green Book.

To calculate the probability of lethality by fragments, a distinction is made between the various mass classes (fragments and debris). For each mass class, calculations are performed: of the velocity at the position of the surrounding objects, depending on its initial velocity and the distance traveled; for people in the free-field, the hit velocity depending on the ballistic perforation velocity of the human

skin; for people in cars the hit velocity, depending on the ballistic perforation velocity of mild steel; and for people in houses the hit velocity, depending on the ballistic perforation velocity of a double brick cavity wall. For each mass class a particular probit function describing the probability of lethality by fragments is specified.

In the calculation of the probability of lethality or injury by blast, it is accounted for ear and lung damage, collapse of houses, window pane crack, and head and total body impact. The data on the collapse of houses are deduced from lethality data of collapsing buildings by earthquakes. The probability of injury is supposed to be twice the probability of lethality. For the calculation of lethality by window pane crack, first the probability of window breakage is calculated and next, the probability of lethality for a person standing behind the window. Again, the probability of injury is supposed to be twice the probability of lethality.

The output of the program consists of an average number of lethalties and injuries in case an accidental explosion of a storage depot occurs. With these results one can decide whether a hazardous situation is acceptable or not.

To enable the application of RISKANAL for the determination of risk contours for UXO disposal operations the following modifications are needed:

- RISKANAL should also account for damage to underground pipelines and building foundations due to ground shock.
- In the risk calculation, it is accounted for the probability of an accidental explosion of an ammunition storage site. Similarly, the probability of an accidental explosion during a disposal operation should be defined, based on the number of disposal operations and the number of accidents. However, for disposal procedures it seems reasonable to assume the probability of an accidental explosion to be 1 (the worst case), since the authorities have the opportunity to take the right protective measures.
- In RISKANAL it is not accounted for the modification of the blast wave as it propagates through an urban area and interacts with surrounding structures. Hence, this shielding effect should be taken into account, see Section 3.
- Criteria for acceptable individual and societal risk for UXO disposal operations should be set by the authorities.

2.4 Preliminary results

By combining CONWEP and RISKANAL safety distances were calculated for the types of ammunition included in the CONWEP data base. The program CONWEP was used to calculate the airblast and the penetration of fragments, based on their mass and initial velocity. In CONWEP, for each bomb, a design fragment mass is defined which is a measure for the large fragments. With RISKANAL the probability of lethality for persons in the free-field and in houses was calculated. The safety distance for people in the free-field was set at such a distance that no ear damage will occur. The safety distance for people in houses was selected at a distance where the fragments do not perforate the wall. It was further assumed that alle people are situated in rooms that do not face the UXO, so that window pane breakage can be accepted. The probability of a hit was set to 1, which is reasonable, since a worst case scenario should be considered in UXO disposal procedures. Hence, the criterium which states that the fragment density is considered unacceptable when more than one fragment falls on an area of 56 m² was not used. The probability of severe injury or lethality was determined only by the impact energy, wich has a threshold of 79 Joules.

By comparing these calculated distances with the ones reported in the VGVK 19 the following trends were noticed:

- For low weight charges, the complete and partly to be evacuated distances as prescribed by VGVK 19 seem reasonable, though the fragment distance is assumed to be too small.
- For heavy charges, the completely and partly to be evacuated distances given in the VGVK 19 seem to be too large for ordinary types of bombs. For Armour Piercing bombs which launch a number of heavy large-size fragments, however, the distances given in VGVK 19 seem reasonable.

This indicates that safety distances should not only be based on the net amount of explosive charge included in the bomb, but also on the fragmentation characteristics, which is accounted for in the new approach.

Summarizing, it can be concluded that a more consistent method for determining guidelines for safety distances for UXO disposal operations has been developed. Furthermore, the assumptions made have shown to be reasonable and to yield realistic safety distances. The following improvements still have to be made:

- first, since there is still a lack of an acceptable risk level for disposal operations as prescribed by the authorities, in our calculations the safety distances were selected at such a distance that all explosion effects were negligible. Obviously, the calculated risk should actually be compared with a prescribed accepted risk level;
- secondly, the reliability of the safety distances obtained from this risk analysis highly depends on the accuracy of the explosion effects predicted by CONWEP. Hence, the accuracy of CONWEP should be examined. Furthermore, the data base included in CONWEP should be extended with more representative types of ammunition, as commonly encountered during disposal operations.

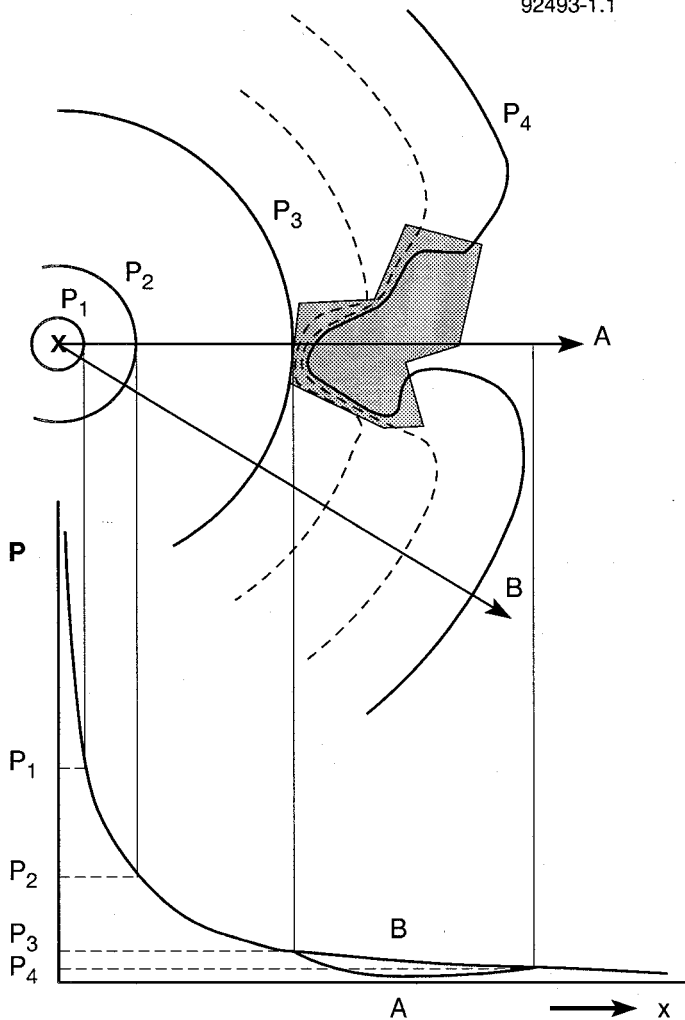
3. Blast propagation through urban areas

3.1 Introduction

The safety distances for residential areas surrounding a potentially-hazardous site, like an UXO, an ammunition storage depot, or a hazardous industrial plant are mainly determined by the strength of the blast wave that is generated by a possible accidental explosion. The destructive power of the blast wave is highly determined by the peak overpressure at the front of the blast wave. The decay of the peak overpressure with distance from the explosion source can be described by simple empirical relations.

The model currently used to determine safety distances is based on the free-field pressure decay of the blast wave, which is representative for the load on a single structure in the free-field. As has been noticed in damage studies, however, houses at the rear of a village are shielded against the blast by the first row of houses, as illustrated in Fig. 1. Due to this shielding effect the damage inflicted to these houses will probably be less severe than predicted by present-day risk analysis and safety distances may be allowed to be shorter. In addition, the blast strength may be reduced by natural obstacles such as forest or slopes in the terrain. On the other hand, a pressure increase may result when the blast waves, which reflect in between the houses, collapse into a single point, for instance in a narrow alley, which is referred to as blast focussing. This modification of the blast wave due to the interaction with surrounding urban structures has not been accounted for in present-day risk analysis. This deficiency might have a significant effect on damage-assessment and the determination of safety distances.

Figure 1. A schematic representation of the local modification of the pressure distribution and potential damage level contours encircling an explosion source due to the presence of urban development.



3.2 Research programme

On behalf of the Dutch Ministry of Housing, Physical Planning and Environment, a research programme was started comprising an experimental and numerical study of blast propagation and interaction with multiple urban structures. The first phase of this study was to investigate what parameters play a major role in the shielding effect. Variables that were expected to mainly influence the degree of shielding are the peak overpressure and duration of the incident blast wave, the structure geometry (flat and pitched roof) and size, the height of the first structure, the number of structures, and the stand-off distance of the structures.

Within the framework of this study experiments on two-dimensional scale models ($5 \times 5 \text{ cm}^2$) of houses and buildings have been conducted with TNO's blast simulator ($40 \times 40 \text{ cm}^2$ test section, 22 m long). The scale models were instrumented with pressure transducers and the shock wave flow was visualized by using interferometric techniques [Absil et al., 1992]. The scale models were loaded with shock waves of 1 and 10 kPa overpressure and durations varying from 25 to 200 ms: 1 kPa is a typical damage criterion for glass failure, while partial demolition of houses can occur at 10 kPa. These relatively low overpressure levels were selected because the emphasis in the present study is on far-field conditions, where shielding effects can reduce the amount of damage inflicted considerably.

For the simulation of three-dimensional blast wave structure interactions, the Computational Fluid Dynamics code BLAST has been developed at TNO-PML [Van den Berg, 1990]. The code solves the Euler equations which describe inviscid compressible flow. The Flux-Corrected Transport scheme is used for optimum description of shocks and contact discontinuities. The code has the capability to calculate the pressure, density, and temperature distribution around structures for a given infalling blast wave. The BLAST code was used to simulate the flows experimentally studied.

3.3 Results

A typical example is shown in Fig. 2, which shows the interaction of a blast wave with two models of buildings. The excellent agreement between the measured interferograms (left) and the isobar pattern as obtained by the numerical simulation (right) indicates that the BLAST code gives a fairly good description of the main features of the shock-wave flow.

The first row shows the vertical shock wave striking the structure from the left. After the shock strikes the first structure, part of the shock is reflected backwards, as shown in the second row. The overpressure in the reflected shock is substantially greater, by about a factor of 2, than that of the incident shock. This pressure difference causes a flow from the region of high to low pressure, resulting in the formation of circular expansion waves at the corners of the structure. The reflected frontal overpressure is relieved by the rarefaction wave that travels down the front surface. At the edge of the structure, viscous separation occurs generating a rolled-up vortex featuring a steep density gradient. In the third row, the shock wave has passed the rear face of the first structure, and the compression wave that bridges the pressure difference between the induced air flow above the buildings and the undisturbed flow in between is shown. The compression wave travels downward across the rear face of the first building and subsequently reflects at the earth's surface. The fourth row shows the complicated wave pattern that develops in between the two buildings. The front of the second building will be hit by the weaker diffracted wave, which indicates that it is shielded against the blast wave by the first building. Next, the infalling wave on the second building is reflected back and the rear face of the first building is hit again, as shown in the last row. This explains why the rear face of a building, which is closely surrounded by other buildings, also shows considerable damage after an accidental explosion.

Figure 2. Comparison of interferograms (left) and calculated isobar patterns (right), for a blast wave of 10 kPa and 60-ms duration.

The overpressure versus time records as calculated with BLAST at the midpoints of the front, top, and rear faces of the structures are presented in Fig. 3. This calculation was made for a blast wave of 10 kPa and 60 ms duration falling in over 10 m high buildings located 15 m apart. In these overpressure signals the complicated wave pattern as seen in Fig. 2 can be readily recognized. The overpressure signal predicted at location 3, at the back of the first building, for instance, shows a sequence of 4 shock phenomena which can be traced in the flow patterns shown in Fig. 2. The first peak is due to the passage of the infalling blast wave. The gradual pressure build-up is the result of the diffraction of the shock around the first structure. The second pressure jump corresponds with the reflection of the primary wave by the ground. The third pressure increase corresponds with the shock wave reflected directly from the second building. This shock wave is immediately followed by a fourth wave, which is the result of the reflection by the second building and subsequently by the ground. Because the second structure is hit by the weaker diffracted wave, the blast load on the front of the second structure will be lower than that on the front of the first structure. The computation shows that the blast overpressure experienced by the front of the second building is about 2 times lower than the reflected overpressure of the undisturbed blast wave endured by the front of the first building. A similar reduction in overpressure was found in the experiments using electric detonators. This shows that a considerable shielding effect can occur under realistic conditions.

Figure 3. Pressure vs time signals at stations 1 to 6 (see Fig. 2) as calculated for a blast wave(10 kPa, 60 ms) interaction with two buildings (10-m high).

The findings of the parametric study can be summarized as follows:

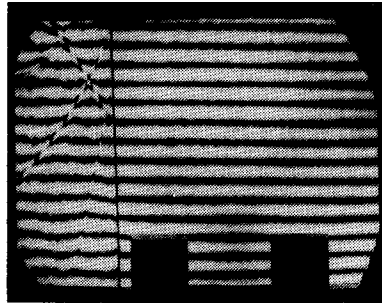
- the shielding effect was found to behave linearly for these rather low overpressures, i.e., nearly the same shielding effect was found for the 1 kPa blast wave as for the 10 kPa blast wave;
- the shielding effect hardly increases after the second structure, i.e., the pressure load on the second, third, and fourth structure is nearly the same;
- the overpressure build-up in between the buildings and the shielding effect were found to be highly dependent on the blast-wave duration and the spacing between the buildings. As the blast wave sustains multiple wave reflections from the surrounding structures cause a pressure increase on the front and rear face of the structures;
- the degree of shielding strongly depends on the height of the first structure;
- the geometry of the roof (i.e. flat versus pitched) only had a minor effect on the pressure-load on the structures.

Summarizing, the parameter study has indicated that due to shielding effects in urban areas, safety distances can probably be smaller than predicted by present-day risk analysis. Furthermore, this detailed information on the blast propagation through urban areas can lead to better and more reliable predictions of the blast damage in residential areas. In addition, it can be used to explain some of the typical damage-patterns as sometimes observed after an accidental explosion.

4. The development of an attenuator for small ordnance items

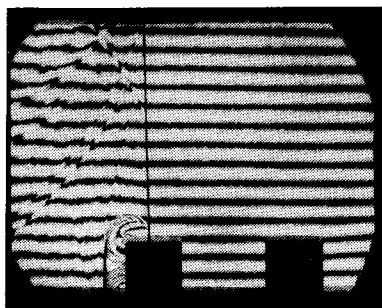
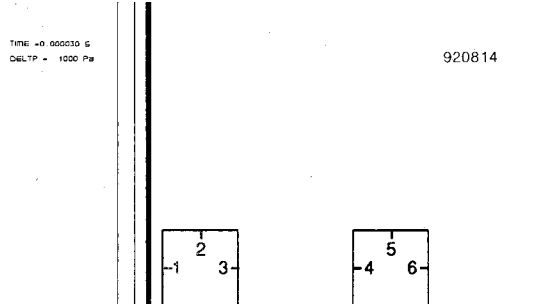
4.1 Introduction

The third project described in this paper is concerned with the development of a blast and fragment attenuator which can be placed over small UXO-items, like bomblets or AP mines, to protect EOD

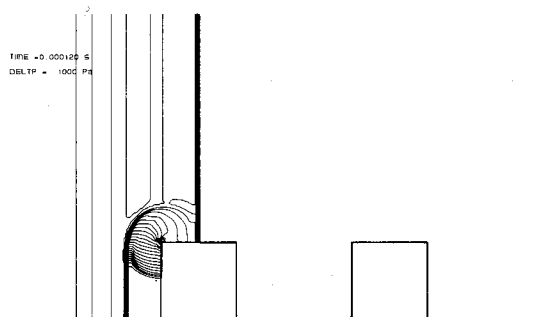


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DELTP = 1000 Pa

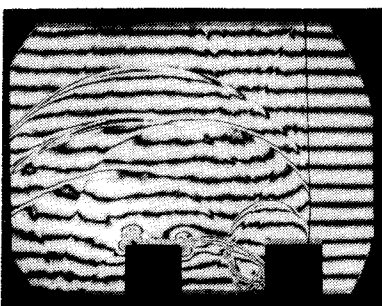
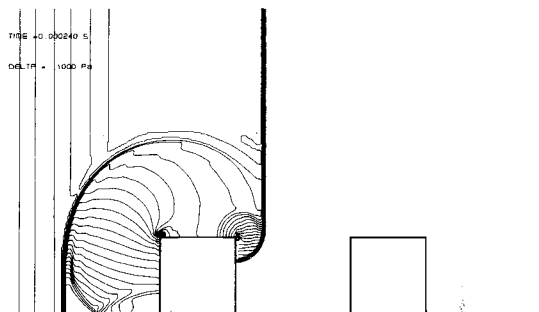
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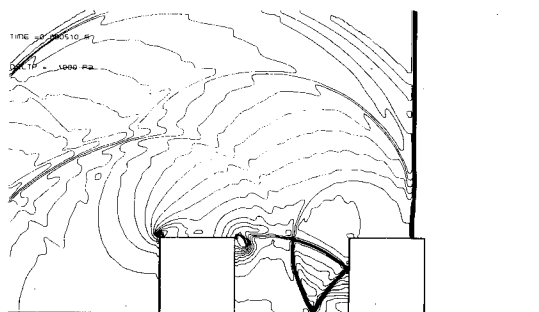
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DELTP = 1000 Pa



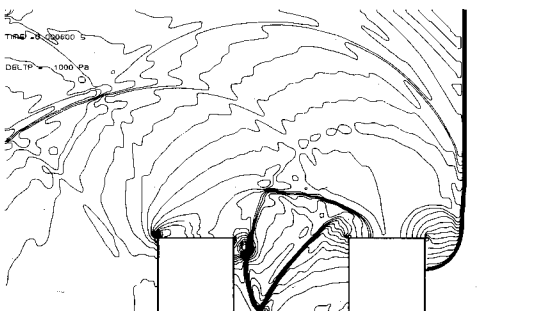
TIME = 0.000240 S
DELTP = 1000 Pa

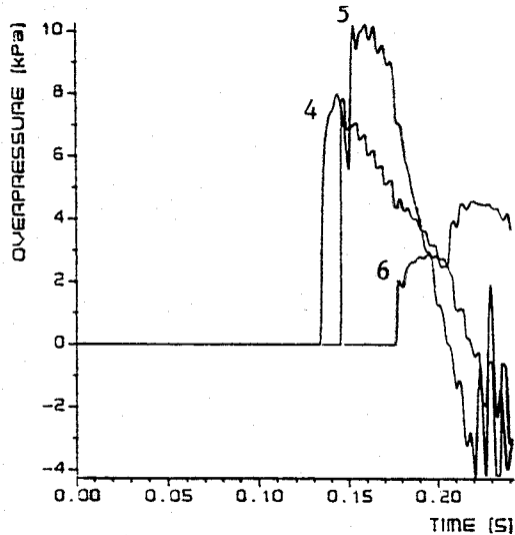
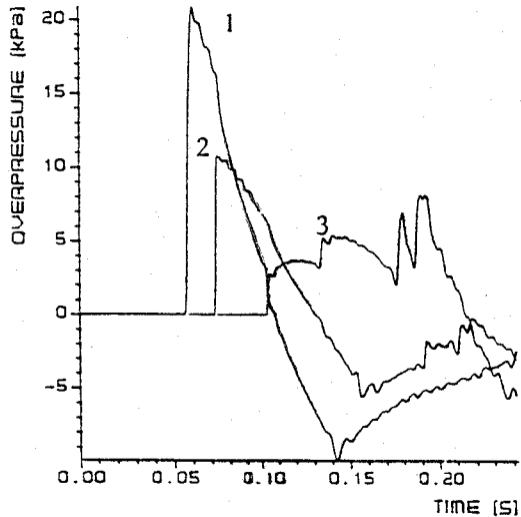


TIME = 0.000360 S
DELTP = 1000 Pa



TIME = 0.000480 S
DELTP = 1000 Pa





personnel or vulnerable objects against explosion effects. Such an attenuator should capture most of the fragments and vent the blast away from demining personnel and threatened objects. By using device, safety distances for UXO disposal operations on small ordnance items can be reduced.

On behalf of the Royal Netherlands Air Force (RNLAf), TNO has started a research programme aimed at developing a bomblet attenuator. The RNLAf has a particular interest in such a device, since clearing operations of bombs and submunitions are needed after an attack of an airfield. It is expected that a few GP bombs will be dropped to cause severe structural damage to the airfield. The submunitions (i.e. bomblets), however, are intended to injure the personnel involved in the repair activities and thereby to delay the repair of the airfield. The threat of random detonations of surrounding bomblets will endanger the EOD personnel working on a large UXO-item like a GP bomb. Usually, the most efficient way to remove the threat exerted by these bomblets is to detonate them by means of an armoured shovel. When the bomblet is situated close to a vulnerable or critical structure (e.g. radar-installation, fuel storage tanks), however, the consequences of a detonation of the bomblet would be unacceptable. In that case it is desirable to have the disposal over a device that can easily be placed over the bomblet and attenuates the blast and fragmentation effects in case it accidentally detonates. Obviously, with the many UN humanitarian demining operations ongoing, this bomblet attenuator could also be of help to EOD personnel involved in mineclearing operations. Such an attenuator can also be used when mines have to be detonated in place, close to high value assets.

The research programme aimed at the development of an attenuator started at TNO-PML was subdivided into the following phases:

- a list of requirements was drawn up;
- a market research was conducted, making an inventory of possible existing attenuators;
- an attenuator will be designed and a prototype constructed;
- this prototype will be tested and validated.

The first two phases of this project have been completed. From the market research it could be concluded that no good bomblet attenuator is available yet. Just very simple devices, like steel cylinders and tires of cars, have been used to this purpose. TNO-PML is aimed at designing a more sophisticated apparatus. Recently some preliminary tests were conducted to quantify the explosion effects of two representative types of bomblets. In addition, some insight was gained into the effectiveness of several simple off-the-shelf attenuators.

4.2 List of requirements

In collaboration with the RNLAf the following list of requirements for an attenuator was drawn up:

- The attenuator should be portable and should be placed over the item by one or at most two persons. Obviously, this puts restraints to the weight of the attenuator. Alternatively, for safety reasons, the attenuator should have provisions to enable the stand-off positioning by a vehicle, by means of a mechanical manipulator.
- It must be possible to place the attenuator over the item without making contact, since this might activate it. Considering the size of ordinary bomblets this would imply that the attenuator should have a width of at least 0.3 to 0.4 m.
- For storage and transportation purposes the layout of the attenuator should be foldable or have a tapered shape. It should be considered that a conical shape of the attenuator will create a lift force launching it up into air.
- Since the attenuator marks a danger area, it should be highly visible. On top only it should be camouflaged otherwise it will be easily spotted by enemy aircraft.
- The attenuator should not have a magnetic signature, since the bomblet might be provided with a magnetic fuze.

- Since the attenuator is expected to withstand only one detonation, it is a consumable product and should therefore be as cheap as possible.
- It should be suited for mass production.

The attenuator is expected to provide protection against the explosion effects of ordinary small items, with explosive charges up to 300 g. It is not expected that it can withstand the effects of shaped charges or large UXO's. At the most the threat of these items can be reduced to a more acceptable level.

4.3 Results of preliminary tests

This preliminary tests were conducted to:

- quantify the explosion effects (blast, fragmentation) of two representative types of bomblets;
- get some insight into the effectiveness of several simple off-the-shelf attenuators.

In Figures 4 and 5 the experimental set-up is shown. Three pressure transducers were used to measure the overpressure signals at distances of 2.5, 5 and 7.5 m away from the charge. At the same distances 3 witness plates, 2 mm thick Aluminium, were positioned to measure the fragment impact. In addition, a video camera was used to record the events.

The BLU-86 and the no.1 MK1 bomblet were selected as being representative for the threat to airfields. The BLU-86 is a small 76.2 mm diameter fragmenting bomblet. It contains a steel housing and a main charge of 113 g cyclotol. The no.1 MK 1 bomblet has a total length of 356 mm and a diameter of 70 mm. It is provided with a chaped charge with a charge weight of 227 g hexolite. The housing is made out of steel. During most of the tests the shaped charge was directed downward into earth. The detonation of the bomblets was achieved by using an electrical detonator nr. 2C2, fixed into 20 g plastic explosives which was molded to the bomblet.

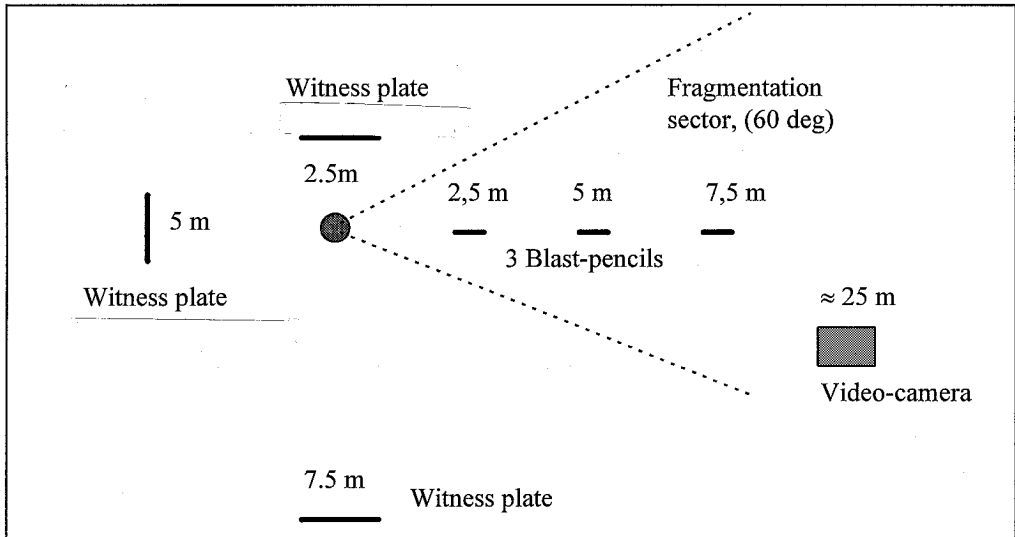
The attenuators tested were cylindrical and had dimensions of the order of 0.3 or 0.4 m in diameter, 0.3 m to 0.5 m in height and 10 mm in wall thickness. The cylinders were made out of steel (weighing over 40 kg), ceramic (8.5 kg) and PVC (10 kg). Furthermore the effectiveness of top-covers, like sandbags and waterbags, was investigated. According to literature [Keenan and Wager, 1992, and Eriksson and Vretblad, 1994] significant reduction in explosion effects (overpressure, fragmentation and gaspressure) can be achieved by using water as an energy absorber. Much detonation energy will be used to vaporize the waterdroplets.

Figure 4. Experimental set-up

Figure 5. Sketch of the bomblet covered by an attenuator

In the following the main results of these tests will be summarized:

- For the unshielded BLU-86 bomblets, the 30 kPa threshold for ear damage was reached within 2.5 m distance. For the no.1 MK .1 this value was reached within 3 m. Several fragments of the MK.1 bomblet perforated the witness plate positioned at 7.5 m, which was not the case for the BLU 86 bomblet.
- The inner diameter of the attenuator should be at least 0.4 m to easily fit over the larger types of bomblets. A height of 0.3 m seems sufficient. No significant reduction in throw out of fragments was found with a 0.5 m high attenuator.
- The weight of the attenuator should at least be less than about 25 kg, since the safe positioning of the 38 kg heavy steel cylinder showed to be difficult. However, it should be noted that low weight cylinders are tempted to be launched.

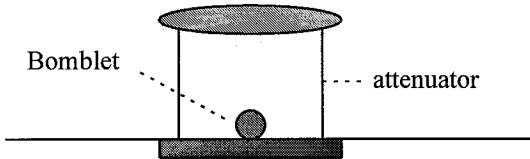


Sand- or waterbag

Bomblet

attenuator

botomplate



- The PVC and the ceramic cylinders broke up into many pieces which could even be found at about 100 m away. In fact, these fragments seemed to be more dangerous than those of the bomblet itself. No PVC or pure ceramic cylinders should be used. Car-tires, however, showed to be promising. The tire was split into a limited number of parts, and many of the fragments were captured in the rubber.
- Without the top cover over the attenuator only a marginal blast reduction of about 10 to 20 % was obtained. With the sandbags as top cover a reduction of about 50% was obtained, while the water bags yielded a blast reduction of about 70%.
- The indent of the fragments in the steel cylinder was found to be about 6 mm. Hence, ballistic protection comparable to that of about 10 mm steel is needed.
- These experiments have shown that simple attenuators can provide acceptable protection against bomblets with charges less than 300 g.
- A very promising concept for an attenuator is a “cake tin” or “turban”. In our tests this concept was simulated by placing the bomblet in a large 51 cm diameter bucket, covering the bomblet up with a small 25 cm diameter bucket, and filling the large bucket with sand or water. With the sand filling, no fragments were found afterwards in the outer bucket, while the blast was significantly reduced up to 20% of its unshielded value. Parts of the buckets were found at distances of up to 20 m, which did not seem a severe problem. With water filling, a reduction of the blast of up to 15% of the unshielded value was obtained.

In the next series of trials the effectiveness of high strength fiber material attenuators will be investigated. These materials are light and have good ballistic properties. Summarizing, this investigation has indicated that it is possible to design an attenuator which has the potential to protect people and vulnerable structures against small UXO items.

5 Conclusions

In this paper it was shown that the current Directives for safety distances for UXO disposal procedures need to be updated. A new approach to the determination of safety distances for UXO disposal procedures was described. In analogy with the method used for the permanent storage of ammunition and explosives, it was suggested to first quantify the possible explosion effects, and then to conduct a risk analysis. The calculated risk can be compared with an accepted level of risk defined by the Government. This approach will lead to more consistent safety distances. However, an evaluation of the accuracy of CONWEP is still needed.

It was demonstrated that a significant shielding effect can occur in realistic situations. This shielding effect strongly depends on the duration of the blast wave, the height of the first building, and the distance between the buildings. Next, it was shown that is possible to design an attenuator which has the potential to protect people and vulnerable structures against small UXO items.

6. Acknowledgement

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7. References

Collection of Common Directives for the Army nr. 19, Directive concerned with disposal of Explosives, Dutch Ministry of Defense, 1974.

US Army TM/NAVORD EODB 60A-1-1-4, Explosive ordnance and disposal procedures, general EOD information, techniques and tools, Section 1-4 protection of personnel and Property, Jan. 1970.

Field Manual FM 9-16, Explosives Ordnance Reconnaissance, Headquarters Department of the Army, USA, 1981.

Manual of NATO safety principles for the storage of military ammunition and explosives, AC/258 Manual. AASTP-1, NATO International Staff, Defence Support Division, May 1992.

Fundamentals of Protective Design for Conventional Weapons, TM 5-855-1.

The Green Book: Committee for Prevention of Disasters by Dangerous Substances: Methods for the determination of possible damage to people and objects resulting from releases of hazardous materials, PR 16, 1990.

L.H.J. Absil, E.A. Bakkum, B. van der Meer, J. Weerheijm, Shearing interferometry and diffraction of weak shock waves by scale models, Proceedings of the 20th International Congress on High Speed Photography and Photonics, Victoria, Canada, 1992.

E. Baker, P. Westine, F. Dodge, Similarity Methods in Engineering Dynamics, Spartan Books, Hayden Book Company Inc. 1973.

A.C. Van den Berg, BLAST 2D - A Code for Numerical Simulation of Two-Dimensional Blast Effects, TNO-PML internal report, 1990.

W.A. Keenan and P.C. Wager, Mitigation of confined explosion effects by placing water in proximity of explosives, 25th DoD Explosives Safety Seminar, Anaheim, California, 1992.

S. Eriksson and B. Vretblad, Blast mitigation in confined spaces by energy absorbing materials, Confortia, Sweden, 1994.